

AI-Enables IoT Based Autonomous Drainage Inspection & Blockage Removal with Real-Time Monitoring

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Abstract: *The AI-Based IoT-Enabled Autonomous Drainage Inspection and Blockage Removal Robot with Real-Time Monitoring is an advanced robotic system developed to address the challenges of manual drainage and sewer maintenance, which often exposes workers to hazardous gases, unhygienic environments, and life-threatening conditions. The proposed system integrates ESP32 microcontroller for motion control and sensor data acquisition, along with Raspberry Pi 4B+ for intelligent image processing and real-time decision-making. By combining robotics, artificial intelligence, embedded systems, and IoT technologies, the proposed model provides a safe, cost-effective, and scalable solution for modern drainage inspection and maintenance applications.*

Keywords: Artificial Intelligence, IoT, Autonomous Robot, Drainage Inspection, Blockage Removal, ESP32, Raspberry Pi, Real-Time Monitoring, Smart Sanitation, Computer Vision.

I. INTRODUCTION

Urban drainage and sewer systems are essential components of modern infrastructure, responsible for transporting wastewater, stormwater, and industrial discharge safely away from residential and commercial areas. However, blockage, sediment accumulation, plastic waste, and structural damage in drainage pipelines often lead to overflow, waterlogging, environmental pollution, and public health risks. Traditional inspection and cleaning methods rely heavily on manual labor, which is time-consuming, inefficient, and dangerous due to direct exposure to toxic gases, contaminated water, and confined spaces [1]. Therefore, there is a growing demand for automated and intelligent solutions for drainage maintenance.

Manual sewer cleaning remains one of the most hazardous occupations in many developing countries. Workers are frequently exposed to poisonous gases such as methane, hydrogen sulfide, and carbon monoxide, which can cause severe respiratory illness or even fatalities. In addition, direct contact with sewage increases the risk of infections and long-term health disorders. Governments and municipalities worldwide are increasingly focusing on mechanized and robotic systems to eliminate unsafe manual scavenging practices and improve sanitation management [2]. Hence, autonomous robotic technologies provide a safer alternative for underground drainage operations.

Recent advancements in the Internet of Things (IoT) have enabled real-time monitoring and smart control of industrial and municipal systems. By integrating sensors, wireless communication, and cloud platforms, drainage robots can continuously transmit data such as gas concentration, humidity, temperature, and equipment status to monitoring centers. IoT-based monitoring improves preventive maintenance, emergency response, and operational transparency. Microcontrollers such as ESP32 have become popular choices due to their low power consumption, built-in Wi-Fi, and cost-effective design for smart robotic applications [3].

Artificial Intelligence (AI) and computer vision technologies have further enhanced the capability of autonomous inspection robots. Using camera modules and image processing algorithms, robots can detect blockages, cracks, corrosion, leakage, and foreign objects inside drainage pipelines with higher accuracy. Platforms such as Raspberry Pi



support real-time image acquisition and AI model execution, enabling decision-making without human intervention. Combining AI with robotic actuators allows systems to automatically initiate cleaning tools such as drills, cutters, or grabbers when blockages are identified [4].

The proposed AI-Based IoT-Enabled Autonomous Drainage Inspection and Blockage Removal Robot with Real-Time Monitoring aims to provide an integrated solution for safe and efficient sewer maintenance. The system combines ESP32-based motor control, Raspberry Pi vision processing, gas and environmental sensing, autonomous movement, and remote monitoring features. This approach minimizes human involvement in hazardous environments, reduces maintenance delays, and improves overall drainage system reliability. Such intelligent robotic systems can play a significant role in future smart city sanitation and infrastructure management [5].

II. PROBLEM STATEMENT

Conventional drainage and sewer maintenance methods depend largely on manual inspection and cleaning, which expose workers to toxic gases, contaminated waste, and unsafe confined spaces. Blockages caused by plastic waste, sludge, and debris often remain undetected until they result in overflow, flooding, and environmental pollution. Existing systems lack real-time monitoring, intelligent blockage detection, and automated cleaning mechanisms. Therefore, there is a need for an AI-based IoT-enabled autonomous robot that can safely inspect drainage pipelines, detect blockages, remove waste, and provide continuous remote monitoring with minimal human intervention.

III. OBJECTIVES

1. To design a robot capable of autonomous navigation inside drainage pipelines.
2. To detect and remove blockages using AI-based vision and mechanical tools.
3. To monitor environmental conditions like gas, temperature, and humidity using sensors
4. To enable real-time data transmission and remote monitoring through IoT.
5. To reduce human involvement in hazardous environments.

IV. LITERATURE SURVEY

Paper 1

V. Ušinskis et al., “Autonomous Sewer Robot: A Laser Marker-Based Obstacle Detection and Measurement System,” *Machines*, 2025.

This paper presents an autonomous sewer inspection robot equipped with a laser marker-based sensing system for obstacle detection and dimensional measurement inside pipelines. The robot improves navigation accuracy and supports autonomous path planning in complex sewer networks. The study highlights the importance of precise sensing for robotic sewer inspection tasks.

Paper 2

Bach Ha et al., “Automatic Defect Detection in Sewer Network Using Deep Learning Based Object Detector,” 2024.

The authors proposed a deep learning-based defect detection model using EfficientDet for identifying cracks, fissures, and structural faults in sewer pipes. A large annotated dataset was used for training, and the model achieved 83% defect detection accuracy. This work demonstrates the effectiveness of AI vision systems in underground infrastructure monitoring.

Paper 3

Nimmagadda Murthy Satyanarayana, “Smart Sewer Robot to Remove Blockages in Sewer,” *Recent Advances in Electrical & Electronic Engineering*, 2023.



This study introduced a mobile robotic platform designed to detect and remove sewer blockages through an underground moving mechanism. The robot helps reduce manual cleaning efforts and improves efficiency in pipeline maintenance. The proposed model can replace traditional hazardous blockage removal methods.

Paper 4

Saniya M. Ansari et al., “Design Study of Smart Robotic Framework for Sewer Conservation,” International Journal of Engineering Trends and Technology, 2022.

This paper proposed a robotic framework using YOLOv3 and YOLOv4 algorithms for real-time blockage detection in sewer pipelines. The robot includes camera sensors and a cutting tool to remove obstructions automatically. The research shows how AI-based vision systems can enhance sewer cleaning operations.

Paper 5

D. Popescul and L. D. Radu, “AI in Phishing Detection: A Bibliometric Review,” Frontiers in Artificial Intelligence, 2025.

Although focused on cybersecurity, this paper demonstrates how AI models are increasingly used for detection and classification tasks in real-world applications. The methodologies discussed can inspire anomaly detection systems in IoT robotics, especially for smart monitoring and intelligent decision-making in autonomous drainage systems.

Comparison Table

Sr. No.	Author / Year	Technique Used	Limitation
1	V. Ušinskis et al. / 2025	Laser Marker Sensing	Limited cleaning mechanism
2	Bach Ha et al. / 2024	Deep Learning (EfficientDet)	Requires high dataset training
3	N. M. Satyanarayana / 2023	Mobile Sewer Robot	Basic monitoring features
4	Saniya M. Ansari et al. / 2022	YOLOv3 / YOLOv4	Higher computational cost
5	Popescul & Radu / 2025	AI Detection Models	Not specific to drainage systems
6	Proposed System / 2026	AI + IoT + Robotics	Initial implementation cost

IV. WORKING OF SYSTEM

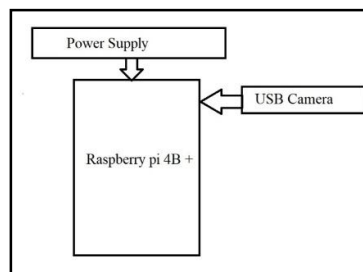


Fig 1: System architecture



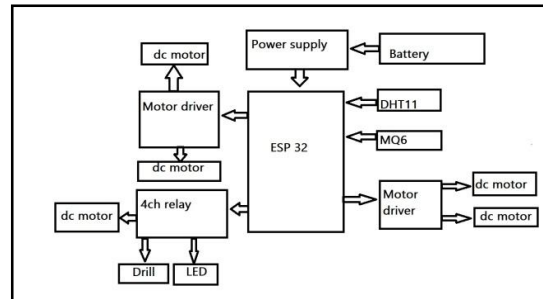


Fig 2: Design of the system

The proposed AI-Based IoT-Enabled Autonomous Drainage Inspection and Blockage Removal Robot is divided into two major hardware sections. The first section is based on the ESP32 controller for robotic movement, sensing, and blockage removal. The second section is based on Raspberry Pi for intelligent monitoring, image processing, and real-time surveillance. Both sections work together to achieve safe and automated drainage maintenance.

A. ESP32 Control and Cleaning Section

This section is centered around the ESP32 microcontroller, which functions as the main control unit of the robotic system. It receives regulated power from the battery supply and distributes control signals to all connected components. The ESP32 manages robotic motion, sensor data collection, and cleaning operations. Its built-in Wi-Fi capability also enables IoT connectivity for remote commands and data transmission.

Environmental sensors are connected to this controller for safety monitoring. The DHT11 sensor measures temperature and humidity inside drainage pipelines, while the MQ6 gas sensor detects hazardous gases such as methane or LPG. These sensors help in identifying unsafe drainage conditions and improve worker safety by generating alerts.

Motor drivers connected to the ESP32 control the speed and direction of DC motors used for wheel movement. This enables the robot to move forward, backward, left, and right inside narrow drainage channels. A relay module is used to switch high-power devices such as the drill or cutter motor. When waste blockage is identified, the cleaning mechanism is activated to remove sludge, plastic, and debris.

B. Raspberry Pi AI Monitoring Section

This section is based on the Raspberry Pi 4B+, which serves as the intelligent processing unit of the robot. It is responsible for handling camera input, executing image processing algorithms, and providing live monitoring. The Raspberry Pi can run artificial intelligence models to detect cracks, obstacles, waste accumulation, and blockage points inside drainage pipelines.

A USB camera is connected to the Raspberry Pi to capture continuous real-time video footage while the robot moves inside the drainage system. The live feed can be transmitted wirelessly to a monitoring dashboard or control room. This allows operators to inspect underground conditions remotely without entering hazardous environments.

LED lights are included in this section to improve visibility in dark drainage passages. The Raspberry Pi also stores inspection data and images for future analysis. By combining AI processing with real-time monitoring, this section improves inspection accuracy and supports autonomous decision-making during cleaning operations.

C. Integrated Working Section

Both ESP32 and Raspberry Pi sections operate together as a complete smart robotic system. The Raspberry Pi detects blockages or hazards through camera analysis, while the ESP32 controls movement and activates the cleaning mechanism accordingly. Sensor data, live video, and robot status are shared through IoT networks for remote



supervision. This integrated architecture provides an efficient, safe, and intelligent solution for drainage inspection and blockage removal.

V. SYSTEM DESIGN

The system design of the AI-Based IoT-Enabled Autonomous Drainage Inspection and Blockage Removal Robot is divided into different functional sections. Each component performs a specific task to ensure smooth inspection, blockage detection, cleaning, and real-time monitoring operations.

A. Power Supply Section

The power supply section provides electrical energy to the complete robotic system. A rechargeable battery is used as the main source of power for controllers, sensors, motors, camera, and relay modules. Voltage regulation circuits ensure stable output and protect components from fluctuations.

B. ESP32 Controller Section

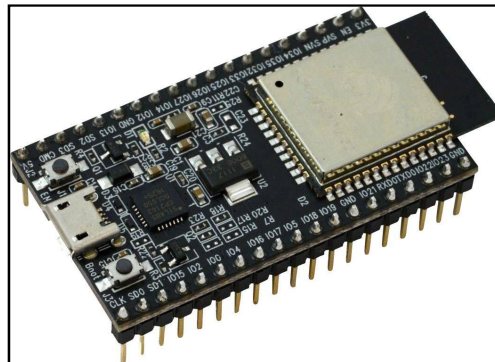


Fig 3: ESP32 microcontroller

The ESP32 microcontroller acts as the primary control unit of the robot. It manages sensor readings, motor movement, relay switching, and wireless communication. Its built-in Wi-Fi module enables IoT connectivity for remote monitoring and control.

C. Raspberry Pi Processing Section

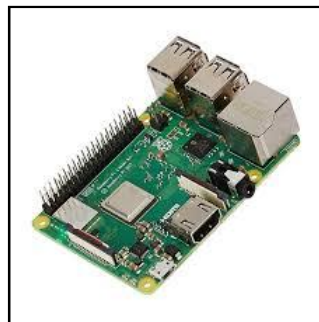


Fig 4: Raspberry Pi 4B+

The Raspberry Pi 4B+ works as the intelligent processing unit. It handles image capture, computer vision algorithms, AI-based blockage detection, and live video streaming. It improves decision-making and inspection accuracy.



D. Sensor Section

The sensor section includes DHT11 and MQ6 sensors. The DHT11 measures temperature and humidity inside drainage channels. The MQ6 sensor detects toxic or flammable gases, helping to maintain safety during operation.

E. Camera Monitoring Section



Fig 5: USB camera

A USB camera is mounted on the robot for real-time visual inspection. It captures live video of drainage pipelines, cracks, waste materials, and obstacles. The camera feed is processed by Raspberry Pi and can be viewed remotely.

F. Motor Driver Section

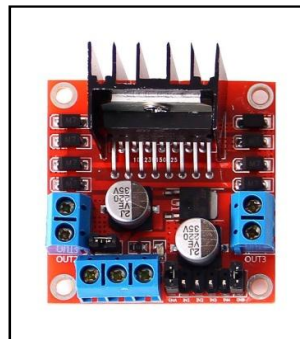


Fig 6: Motor driver

The motor driver section interfaces between the controller and DC motors. It controls motor speed and direction based on commands from ESP32. This section ensures proper robotic movement inside narrow drainage areas.

G. Mobility Section

The mobility section consists of wheels and DC geared motors. It allows the robot to move forward, backward, and turn inside drainage channels. Strong wheels help the robot travel on wet and uneven surfaces.

H. Cleaning Mechanism Section

The cleaning section includes a drill, cutter, or rotating blade connected through a relay module. It removes sludge, plastic waste, and solid blockages when activated. This section reduces manual cleaning effort.



I. Communication Section

The communication section uses Wi-Fi technology for IoT-based data transfer. Sensor readings, robot status, and live video are sent to a remote dashboard or mobile application. It enables real-time supervision and control.

J. Monitoring and Alert Section

This section provides instant alerts when harmful gas levels, abnormal temperature, or blockage conditions are detected. Notifications help operators take quick action and improve safety.

K. Integrated Operation Section

All sections work together as a smart robotic system. Sensors collect environmental data, the camera performs inspection, controllers manage movement, and the cleaning mechanism removes blockages. The integrated design ensures efficient and autonomous drainage maintenance.

VI. RESULTS

The developed AI-Based IoT-Enabled Autonomous Drainage Inspection and Blockage Removal Robot demonstrated effective performance during testing in a simulated drainage environment. The robot was able to move smoothly through narrow channels, capture real-time video footage, and detect obstacles or waste materials using the camera module. Environmental sensors successfully measured temperature, humidity, and harmful gas levels, while the IoT communication system transmitted live data and status updates to the monitoring interface without significant delay.

The blockage removal mechanism operated efficiently by clearing plastic waste, sludge, and small debris when activated. The coordinated operation between ESP32 and Raspberry Pi improved autonomous navigation, inspection accuracy, and response time. The system reduced the need for manual intervention in hazardous drainage conditions and showed potential for practical implementation in municipal sewer maintenance, smart city sanitation, and industrial drainage monitoring applications.

Model prototype

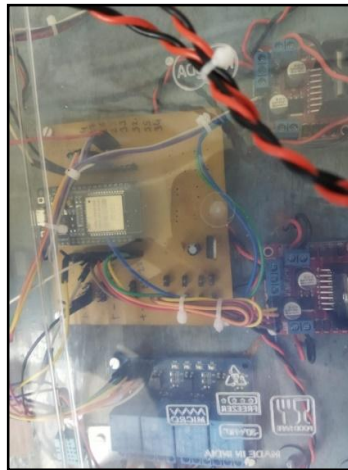


Fig 7: Model view 1



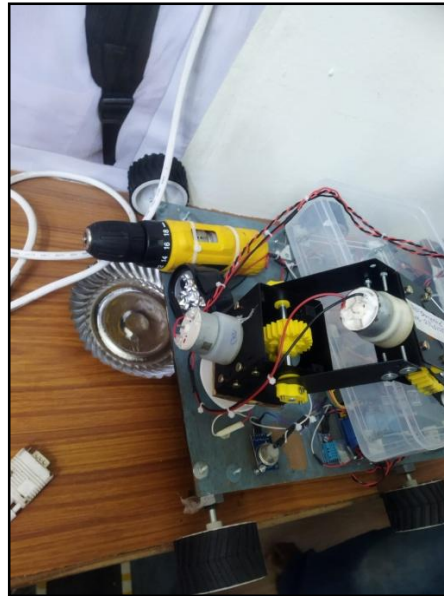


Fig 8: Model view 2



Fig 9: Model view 3



VII. CONCLUSION

The AI-Based IoT-Enabled Autonomous Drainage Inspection and Blockage Removal Robot with Real-Time Monitoring provides an effective and modern solution for improving drainage and sewer maintenance operations. By integrating ESP32 for motion and sensor control, Raspberry Pi for intelligent image processing, IoT for remote communication, and a mechanical cleaning mechanism for blockage removal, the system successfully reduces the need for hazardous manual cleaning practices. It is capable of detecting waste accumulation, monitoring environmental conditions, identifying harmful gases, and transmitting live video data for remote supervision. The robot enhances operational safety, increases cleaning efficiency, minimizes maintenance time, and supports smart sanitation management. The overall system demonstrates strong potential for use in municipal drainage networks, industrial pipelines, and future smart city infrastructure where automated, safe, and reliable maintenance solutions are required.

VIII. FUTURE SCOPE

The future scope of the AI-Based IoT-Enabled Autonomous Drainage Inspection and Blockage Removal Robot can be expanded by integrating advanced artificial intelligence models for more accurate blockage detection, crack analysis, and predictive maintenance of drainage systems. The robot can be upgraded with GPS and advanced navigation technologies for fully autonomous path planning in large sewer networks. Additional sensors such as water level, pH, and toxic chemical sensors can be included for better environmental monitoring. Cloud-based data storage and analytics can be implemented to maintain historical inspection records and generate maintenance schedules. The system may also be enhanced with robotic arms, stronger cutting tools, and automatic waste collection units for handling complex blockages. In the future, solar charging systems and longer battery backup can improve operational time, while 5G communication can provide faster real-time monitoring for smart city sanitation management.

REFERENCES

1. C. Li, "Robotic technologies for sewer inspection," *Chemical Engineering Journal Advances*, vol. 26, 2026.
2. G. Villinger and A. Reiterer, "Robotic systems for sewer inspection and monitoring tasks: Overview and novel concepts," *IEEE Sensors Journal*, 2025.
3. B. Ha, B. Schalter, L. White, and J. Koehler, "Automatic defect detection in sewer network using deep learning based object detector," *arXiv preprint arXiv:2404.06219*, 2024.
4. C. Thrainer, "AI-Based Culvert-Sewer Inspection," *arXiv preprint arXiv:2601.15366*, 2026.
5. K. Murata and A. Kakogawa, "Development of a practical articulated wheeled in-pipe robot for force main inspection of sewer pipes," *arXiv preprint arXiv:2411.03660*, 2024.
6. S. V. Gaikwad, A. Khaire, M. Kanawade, S. Kotkar, and M. Kanawade, "IoT Based Autonomous Drainage Inspection and Blockage Removal Robot with Live Monitoring System," *TIJER*, vol. 13, no. 3, pp. a750–a753, 2026.
7. G. Hemalatha, A. Akileshwaran, A. Vardhan, V. Kumar, and P. Parthiban, "Artificial Intelligence-Based Smart Drainage Cleaning Robot," *IRJET*, vol. 11, no. 5, pp. 76–80, 2024.
8. T. McKenna et al., "Towards Autonomous Navigation of In-Pipe Inspection Robots," *Frontiers in Robotics and AI*, vol. 9, 2022.
9. K.-W. Jeon et al., "Development of an In-Pipe Inspection Robot for Large-Diameter Water Pipes," *Sensors*, vol. 24, no. 11, p. 3470, 2024.
10. J. K. Mills et al., "Adapting Mechanisms for In-Pipe Inspection Robots: A Review," *Applied Sciences*, vol. 12, no. 12, p. 6191, 2022.
11. Y. Zhang et al., "A Review of Worm-Like Pipe Inspection Robots: Research, Trends and Challenges," *Soft Science*, vol. 2, no. 1, pp. 49–63, 2023.
12. S. Sugin et al., "A Review on Wheeled Type In-Pipe Inspection Robot," *International Journal of Mechanical Engineering and Robotics Research*, vol. 11, no. 10, pp. 745–754, 2022.



13. N. Reyes-Dorta, P. Caballero-Gil, and C. Rosa-Remedios, "Detection of malicious URLs using machine learning," *Wireless Networks*, vol. 30, pp. 7543–7560, 2024.
14. D. Popescul and L. D. Radu, "AI in phishing detection: A bibliometric review," *Frontiers in Artificial Intelligence*, vol. 8, 2025.
15. M. A. Rahman et al., "A Comprehensive Review on Pipe Inspection Robots," *International Journal of Mechanical Engineering*, vol. 10, no. 3, 2021.
16. N. Botteghi et al., "Towards Autonomous Pipeline Inspection with Hierarchical Reinforcement Learning," arXiv preprint arXiv:2107.03685, 2021.
17. E. Lucet and F. Kfoury, "ACES: A Teleoperated Robotic Solution to Pipe Inspection from the Inside," arXiv preprint arXiv:2405.09925, 2024.
18. J. Guo, Z. Wang, and W. Bai, "Learning Quadrupedal Robot Locomotion for Narrow Pipe Inspection," arXiv preprint arXiv:2412.13621, 2024.
19. N. K. Chhabhaiya and P. Bhojane, "Developing an IoT-Based Internal Pipe Inspection Robot," *IJARESM*, vol. 11, no. 6, 2023.
20. Kenzhekhan et al., "Design and development of an in-pipe mobile robot for pipeline inspection with AI defect detection system," *Proceedings of ICCAS*, pp. 1–6, 2023.

